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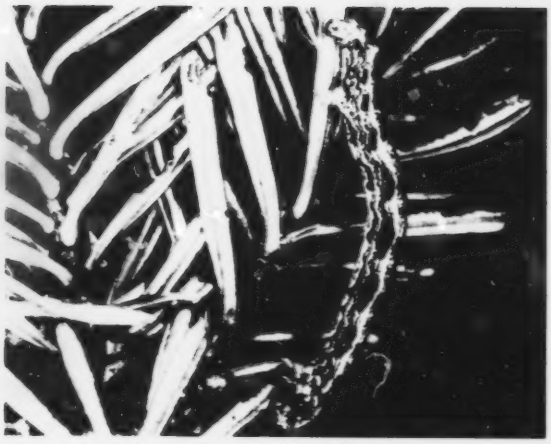
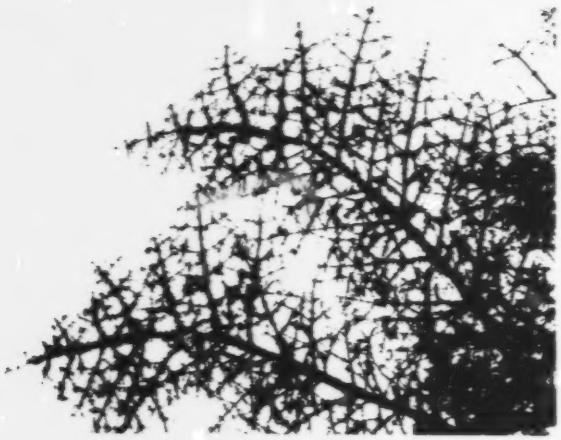
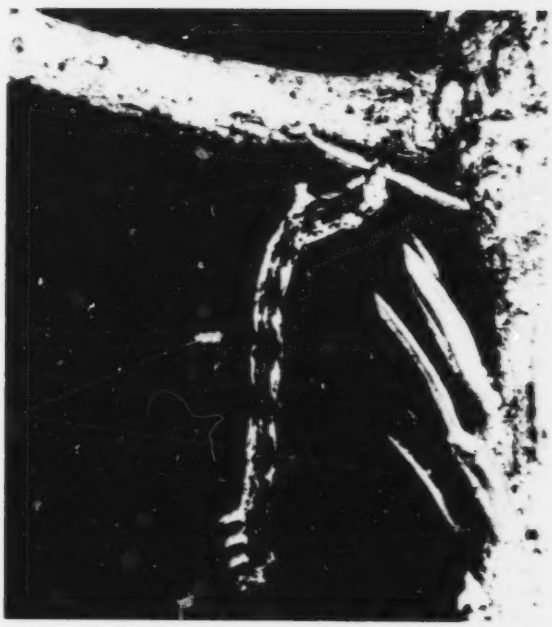
by Imre S. Otvos, L. J. Clarke and D. S. Durling







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NEWFOUNDLAND FOREST RESEARCH CENTRE
ST. JOHN'S, NEWFOUNDLAND
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ABSTRACT

This report reviews the six eastern hemlock looper outbreaks that are known to have occurred in Newfoundland this century. The report gives the periods of the outbreaks, size of the areas infested and the severity of the damage. It describes the chemical control operations conducted against the hemlock looper in 1968 and 1969. The natural control factores weather, avian predators, parasites and diseases and their effect in the population fluctuation of the hemlock looper are discussed. The report also reviews and summarizes the characteristics and pattern of looper outbreaks in Newfoundland.

RÉSUMÉ

Dans ce rapport on réexamine les six infestations de l'arpenteuse de la pruche de l'est qui ont eu lieu à Terre-Neuve pendant ce siècle. On y traite des périodes des dites infestations, de l'étendue infestée et du degré du dommage. Les opérations de contrôle chimique y sont aussi décrites; opérations entreprises contre l'arpenteuse de la pruche de l'est en 1968 et en 1969. On examine les facteurs naturels de contrôle, tels que: influences météorologiques, oiseaux-prédateurs, parasites et maladies, y compris leur effet sur la fluctuation de la population, de la dite arpenteuse. C'est aussi une revue et un résumé des traits caractéristiques et du mode d'évolution de ces infestations à Terre-Neuve.

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A HISTORY OF RECORDED EASTERN HEMLOCK LOOPER OUTBREAKS IN NEWFOUNDLAND

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INTRODUCTION

The eastern hemlock looper, Lambdina fiscellaria fiscellaria (Guen.), is a defoliating insect native to North America. It is distributed in Canada from Newfoundland in the east to Alberta in the west (Prentice 1963). Outbreaks have been recorded in Newfoundland over the past 60 years and have also occurred in the Maritime Provinces, Quebec and Ontario. The biology of the looper in Newfoundland has been described by Carroll (1956) and more recently by Otvos et al. (1971).

The egg is the overwintering stage; eggs are deposited singly on a variety of substrata in the forest. Hatching of larvae occurs over an extended period from early June to about mid-July. The looper has four larval instars in Newfoundland (Carroll 1956) and there is considerable overlap in development among larval instars. The period of larval development is about 50 days. Pupation begins in late July, and the pupal period lasts about 3 weeks. Emergence of the adults begin in late August and moths can be found in the field until late fall with peak abundance in early September.

The larvae feed on a variety of forest tree species but the principal host is balsam fir, Abies balsamea (L.) Mill., which comprises about 50% of the merchantable softwood volume on the Island (Anon. 1974). The larvae are wasteful feeders, usually consuming only part of a needle before moving on to feed on another needle. The partly eaten needles die and give the characteristic reddish-brown color of the damaged stands.

Recent surveys conducted by the Forest Insect and Disease Survey have indicated that hemlock looper numbers have generally increased across the Island, especially in areas where populations of the spruce budworm decreased (Clarke et al. 1975, 1976 and 1977). This trend indicates that another outbreak may be developing. This report has therefore been prepared to summarize available information on past outbreaks, to examine population dynamics of the insect and discuss the possibilities for forecasting the occurrence of outbreaks.

HISTORY OF OUTBREAKS

To facilitate the description of the outbreaks, the geographical divisions, the location of major place names and forest ranger districts, referred to in this report are given in Figures 1 and 2. The distribution of the productive forest land and the proportions of softwoods, mixed woods, and hardwoods in the forest inventory regions of the Island are presented in Figure 3.

1910 - 1915

The report of the Dominion Entomologist for Canada in 1912 contains the first record of a hemlock looper outbreak in Newfoundland as follows:

> "An unusual outbreak of a geometrid, the caterpillar of which defoliated many thousands of acres of balsam fir in Newfoundland was reported to us ... and on investigation it was found that the insect was Therina fiscellaria" (Hewitt 1913).

The extensive area of damage suggests that the outbreak probably had started at least two years prior to being reported. Further detail is provided on the location and extent of the damage by Swaine* (1925) who mentions the severe outbreak that killed "nearly all the balsam fir over many square miles" (1 sq. mile = 2.59 km^2 = 259 hectares) at four locations on the Port au Port Peninsula, on the coast below Bonne Bay, on the north shore of Deer Lake in western Newfoundland and near Badger in central Newfoundland (Table 1, Figure 4). This outbreak apparently collapsed in 1915, but no mention is made of the cause for the collapse.

1920 - 1926

A hemlock looper outbreak was recorded by Swaine (1925) during a three week inspection trip to Newfoundland at the invitation of the Department of Natural Resources of Newfoundland. He reported several infestations at a number of locations on the Avalon Peninsula (Figure 4). He stated that one of these, near St. John's, "had been in progress for at least five years .... A large part of the fir, and spruce mixed with the fir, has already been killed ... and stands severely defoliated in 1925 ... include a great number of weakened trees that will unquestionably die within the next few years" (Swaine 1925). He also mentioned another infestation on the west coast between Parsons Pond and St. Genevieve's Bay on the Northern Peninsula which killed an estimated 723 000 m^3 (300,000 cords) of pulpwood (Table 1, Figure 4). This outbreak probably did not collapse at least until 1926.

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*Swaine, J.M. 1925. Report of an inspection of Newfoundland forest areas in 1925 (unpublished).

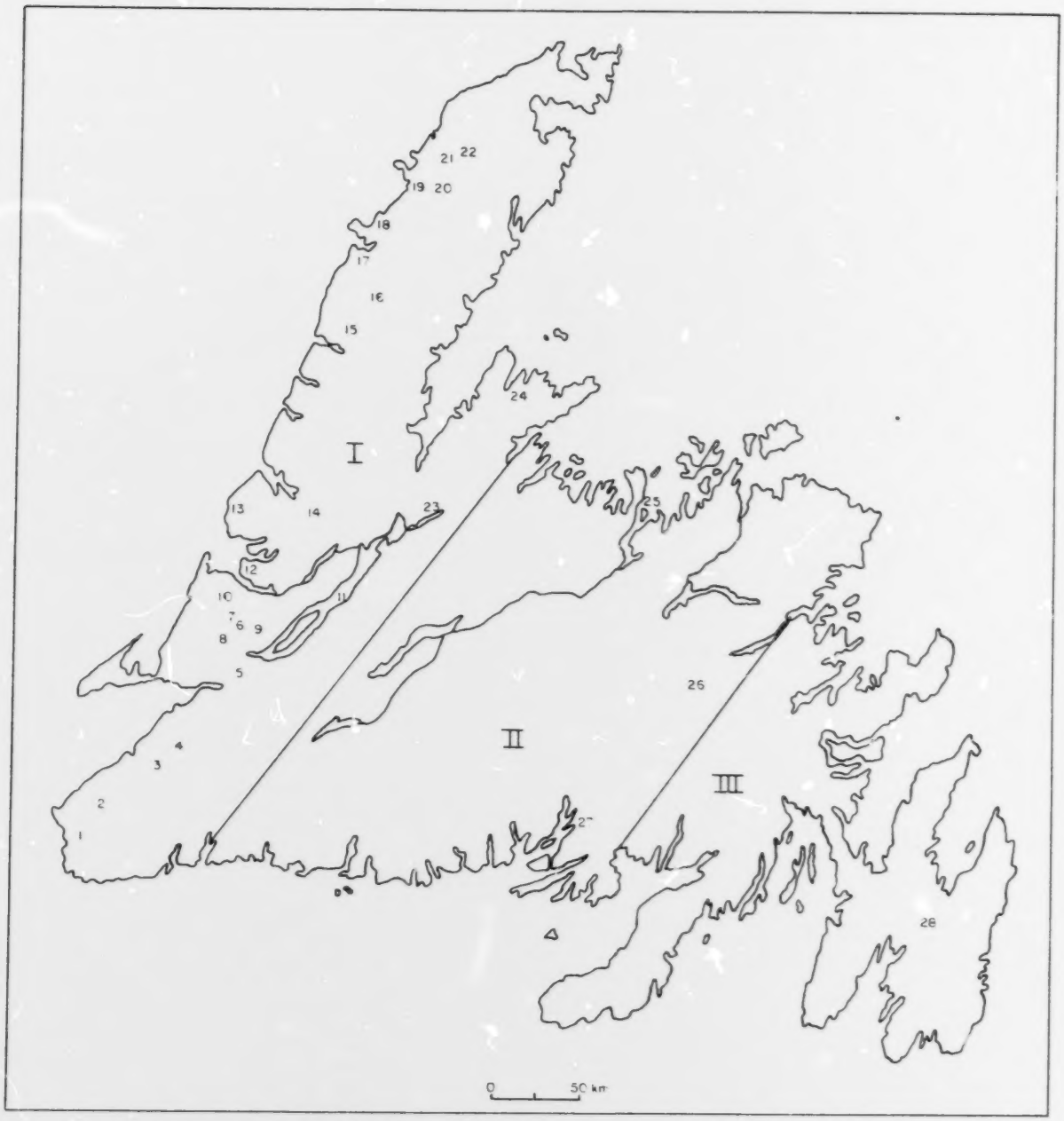

Fig. 1. Major geographic divisions and locations of major place names referred to in this report.

Legend: I Western, II Central, III Eastern

1 - Tompkins
2 - Codroy Valley
3 - Crabbes River
4 - Robinsons River
5 - Bottom Brook
6 - Georges Lake
7 - Spruce Brook
8 - Gallants
9 - Gull Pond
10 - Serpentine Lake
11 - Grand Lake
12 - McIvers
13 - Shoal Point
14 - Bonne Bay Pond
15 - Brians Pond
16 - Flat Ponds
17 - River of Ponds
18 - Bustards Cove
19 - Castors River
20 - Leg Pond
21 - Ten Mile Lake
22 - Round Lake
23 - Birchy Lake
24 - Ming's Bight
25 - Birchy & Thwart Islands
26 - Deer Pond
27 - Conne River
28 - Salmonier Valley

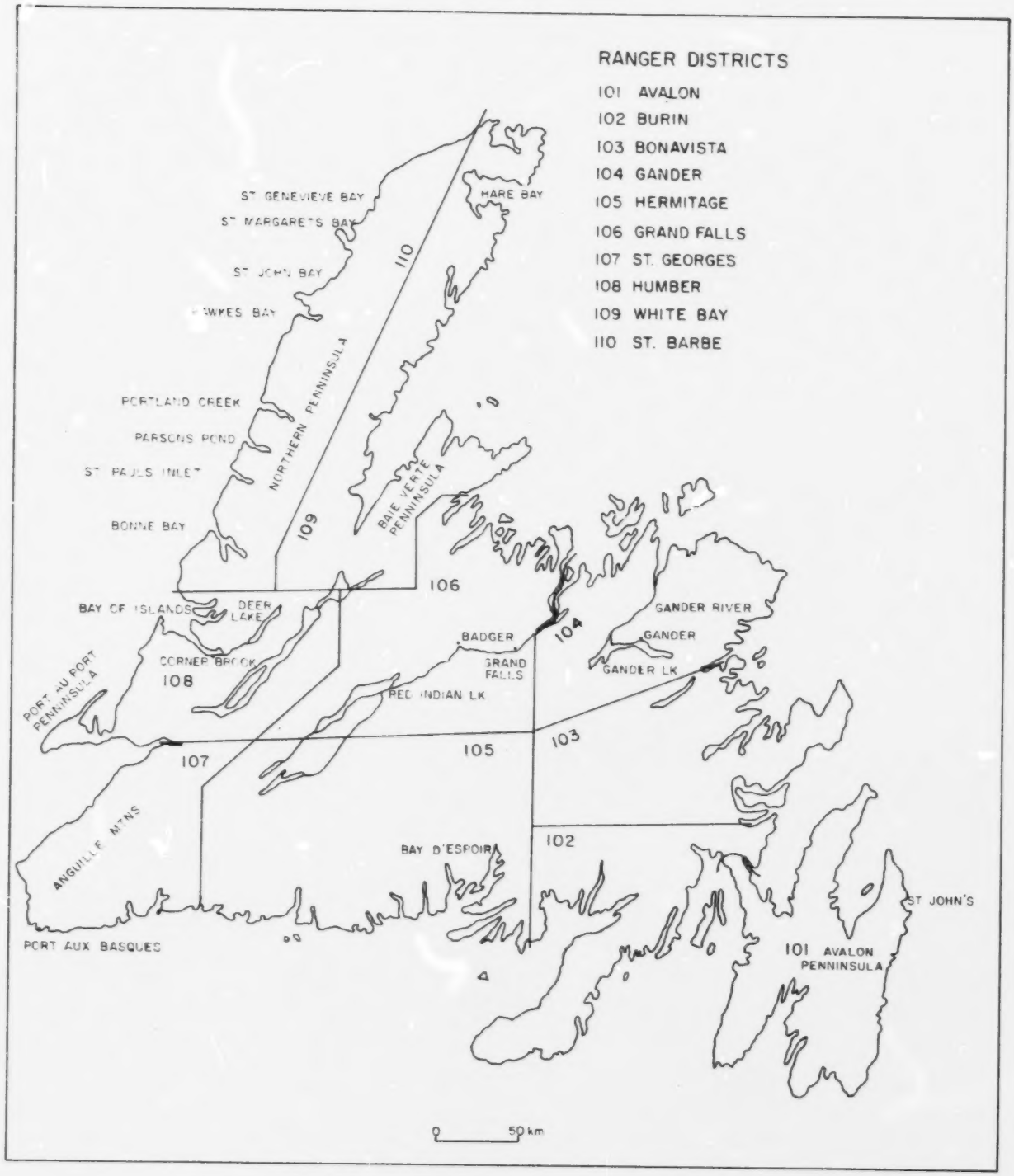

Fig. 2. Forest Insect and Disease Survey Ranger Districts with some of the major places referred to in this report.

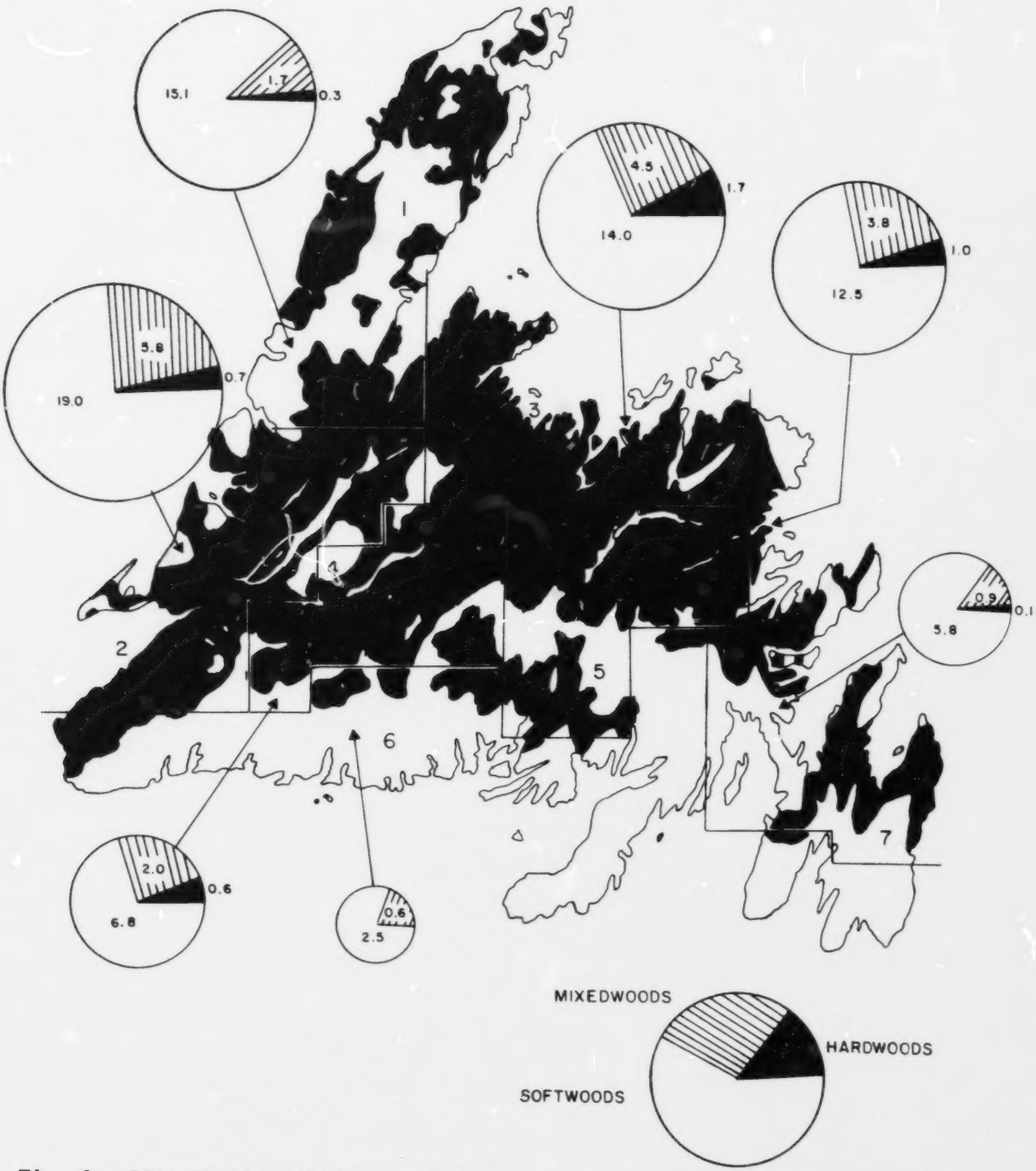

Fig. 3. Distribution of the productive forest land on the island of Newfoundland with Forest Inventory Regions.

The sizes of the circles indicate the volumes of wood, in millions of cunits, and the proportion of softwoods, hardwoods, and mixed woods in each of the inventory regions (1 cunit = 2.8 m^3) (After Page et al. 1974 and Anon. 1974).

Table 1.- Summary of the six known hemlock looper outbreaks in Newfoundland.

Outbreak parameters	Outbreak period					
	1910-15	1920-26	1929-35	1946-55	1959-64	1966-72
Total area infested						
acres	30,000+	20,500	140,600+	315,300	54,000	2,051,800
hectares	12 100+	8 300	56 900	127 600	21 800	830 300
Defoliation:*						
Light - acres	unknown	unknown	unknown	unknown	unknown	480,800
" - hectares	"	"	"	"	"	194 600
Moderate - acres	"	"	"	"	"	558,500
" - hectares	"	"	"	"	"	226 000
Severe - acres	30,000	probably	probably	extensive	10,700	742,700
" - hectares	12 100	all	extensive	"	4 300	300 500
Estimate of mortality:						
acres	**3,000	**15,000	-	**30,100	**25,000	**272,900
hectares	1 200	6 100	-	12 200	10 100	110 400
cords	***75,000	***300,000+	***10,000+	***500,000	***600,000	***3,482,400
cubic metres	180 800	723 000	24 100	1 205 000	1 446 000	8 633 500
Estimated volume salvaged:						
acres	unknown	unknown	unknown	unknown	-	45,300
hectares	"	"	"	"	-	18 300
cords		"	"	"	40,000	596,400
cubic metres	"	"	"	"	96 400	1 437 400
Interval in years between:						
1st outbreak years	?	11	10	18	14	7
beginning and peak population level	3	4	5	7	3	4
Duration of outbreak in years	6	7	7	9	6	7

Cont'd ...

Table 1 - Concluded

Outbreak parameters	Outbreak period					
	1910-15	1920-26	1929-35	1946-55	1959-64	1966-72
Factors credited with collapse of outbreak	unknown	unknown	unknown	undetermined wilt disease, parasitism, starvation, salvage.	starvation, disease, parasites.	chemical control, starvation, fungi, parasites, predators.
References	Hewitt 1913	Swaine 1925	Balch 1942	Carroll & Parrott 1954; Carroll 1956	Annual District Survey Reports 1959-1965	Otvos, Clark, & Clarke 1971; Annual District Survey Reports 1966-1972 Otvos 1973

*Defoliation classes: Light: 6-25% of the needles damaged, Moderate: 26-75%, Severe: 76-100%.

**Areas measured from 1:50,000 maps to which the outbreaks were transcribed from reports. Data for the last two outbreaks show net productive forest land, while gross total areas are shown for the previous outbreaks. Areas are given both in acres and hectares for easier comparison with old records.

***Volumes were calculated by using the best yield estimate per acre for the area, this varied from 12.5 to 25 cords per acre in some of the older mature stands on the Northern Peninsula. All tree species are included. 1 cord = 2.41 m^3 (solid).

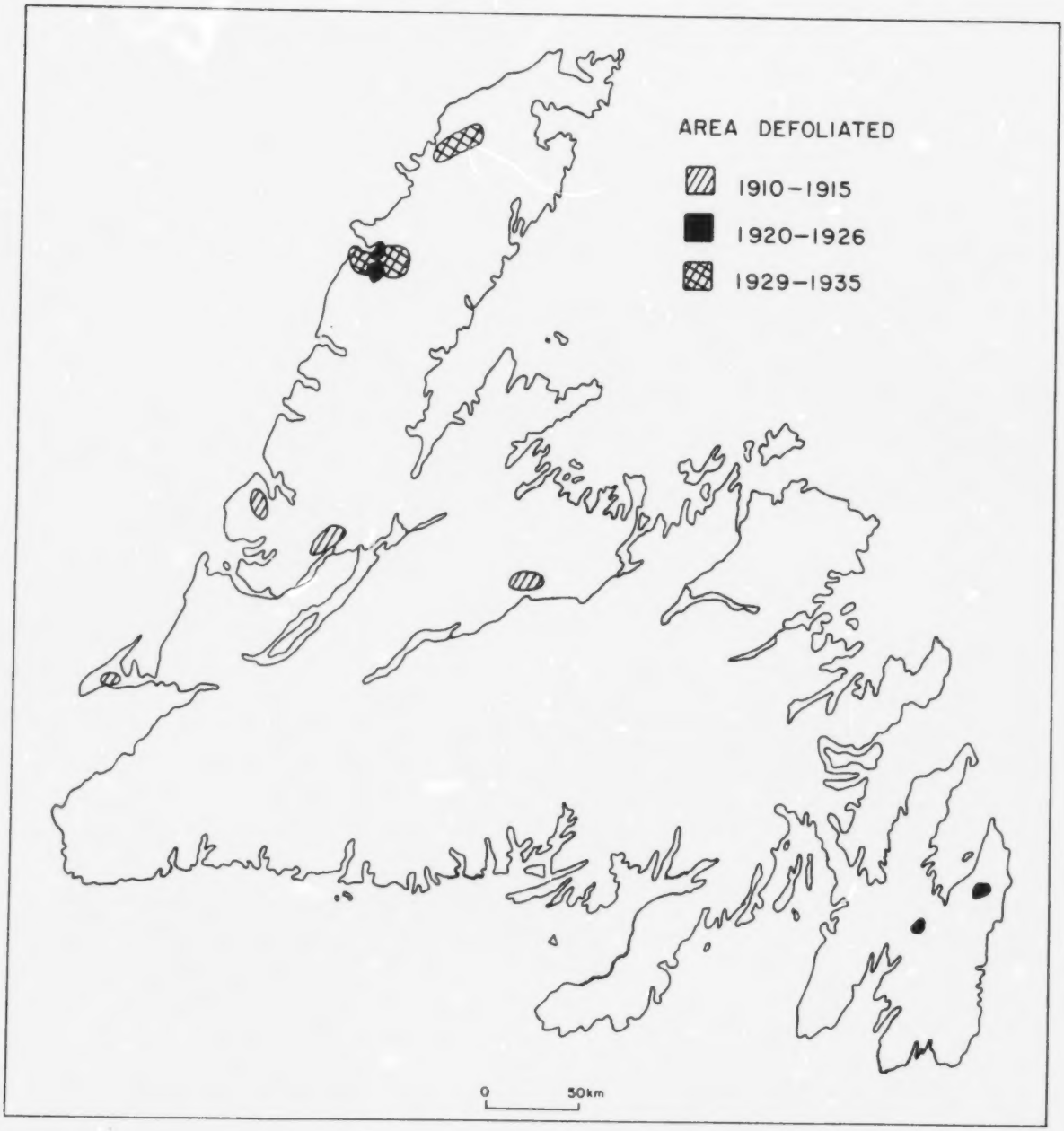

Fig. 4. Areas defoliated by the eastern hemlock looper during the 1910-1915, 1920-1926 and 1929-1935 outbreaks.

1929 - 1935

Extensive loss of balsam fir stands were reported by Bowater Pulp and Paper Company personnel in the St. Barbe District (Figure 2) near River of Ponds and Ten Mile Lake and between Parsons Pond and St. Genevieve's Bay between 1930 and 1935 (Table 1, Figure 4). Although both black and white spruce were infested, tree-killing was not observed in stands with a large percentage of spruce even under outbreak conditions (Balch 1942*; Carroll 1956). It is possible that infestations occurred at other locations during this outbreak period but were not recorded, and it can be assumed that the outbreak began at least one year earlier than it was noticed.

1946 - 1955

Looper populations reached epidemic levels in 1947 after two years of increasing numbers of larvae in the samples and defoliation was reported at several locations. However, it is assumed that this outbreak started at least in 1946 considering the extent of the defoliated area reported. More than 20 separate recognizable infestations were identified by location (Figure 5) and the larger ones are described individually.

Bay d'Espoir

The outbreak probably started with the infestation near Bay d'Espoir and was reported to cover about 24.6 km^2 (9.5 sq. miles) in the Conne River, Twillick Brook watersheds in 1947. About half of the almost pure balsam fir stands in this area was moderately defoliated (40%-50%), and in some localities defoliation reached 100% (Read 1947). The following year, in 1948, the main part of the infestation covered approximately 83 km^2 (32 sq. miles) excluding two neighbouring smaller infestations 3 hectares (8 acres) (Milltown Point) to 4 hectares (10 acres) (Conne River) in size. In the most severely infested stands, over 1,000 larvae per tree sample were counted (Carroll 1948; Reeks et al. 1948). This infestation collapsed in 1949 and no defoliation was recorded during an aerial survey of the area in the fall. Dead trees were common along the streams, but most of the dead timber was salvaged from this area (Reeks, Carroll and Sheppard 1949; Carroll 1956). No explanation is given for the collapse of this infestation. In 1947, pupal parasitism in the Bay d'Espoir area was about 33% in addition to the "high mortality" from unknown causes (Reeks et al. 1947). It is postulated that collapse of the infestation was caused by the combined effect of parasites and by the unknown mortality factor.

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* Balch, R.E. 1942. Report on an inspection of forest areas in Newfoundland in 1942. Forest Biology Laboratory, Fredericton, N.B. (Unpublished, 13 p.).

Fig. 5. Areas defoliated by the eastern hemlock looper during the 1946-1955 outbreak.

Birchy and Thwart Islands

This infestation was first discovered in 1948 on the eastern part of Thwart Island and it was estimated that the equivalent of 38 560 to 48 200 m^3 (16,000 to 20,000 cords) of balsam fir and white spruce had been completely defoliated in that year (Carroll 1948). In 1949 the infestation spread to the adjacent mainland area of Bay of Exploits and covered a total area of about 13 km^2 (5 sq. miles). Approximately 60% to 75% of the balsam fir had been killed by 1948 and most of the remaining balsam fir trees were completely defoliated in 1949. Even some black spruce trees growing in the almost pure stands of mature balsam fir were killed. This infestation caused the most damage in 1949 and some of the defoliated trees were also attacked by bark beetles. The looper infestation appeared red to grey during an aerial survey in the fall (Reeks, Carroll and Sheppard 1949; Reeks, Forbes and Cuming 1949). In 1950 the looper caused light to moderate defoliation in this area and some of the trees showed signs of recovery.

An undetermined "wilt" disease was recorded as causing much larval mortality in 1949 and 1950 (Sheppard 1950) and was thought to be responsible for terminating the infestation in 1950. An unknown portion of the trees killed in this area was salvaged (Carroll 1956). Although a polyhedrosis virus, extracted from diseased looper larvae by pathologists of the Insect Pathology Research Institute, Sault Ste. Marie, Ontario, was introduced at Hunt's Cove, Gander Lake (80 km southeast of Thwart Island) and at Twillick Brook and Conne River near Bay d'Espoir in 1948 (Reeks et al. 1948), it is highly unlikely that it was the same as the "undetermined wilt disease" reported from Thwart Island area in 1949 (Reeks, Carroll and Sheppard 1949), and was reported from all infestations visited in 1950 (Sheppard 1950). The distance between these widely separated locations and the nearest point of virus dissemination makes it improbable that the introduced virus was responsible for the widespread epizootic.

The infestation on Birchy Island in Exploits Bay was reported in 1948 when about 30% of the fir and spruce on this island had been killed. It was estimated that this infestation had been in progress for 2 years or more (Reeks et al. 1948).

Northern Peninsula

Scattered infestations of various sizes occurred from the north side of Bay of Islands along the northwest coast to St. Margaret's Bay, a distance of about 217 km (135 miles). The insect was reported to be present in most of the heavily wooded sections from St. Paul's Inlet northward, while in the southerly areas it was only present in small isolated spots (Sheppard 1950).

Several infestations were noted by Sheppard during an aerial survey in 1949 along the west coast of the Northern Peninsula

between St. Paul's Inlet and Hawkes Bay (Reeks, Carroll and Sheppard 1949). At St. Paul's Inlet and at Parsons Pond the infestation may have started as early as 1945. By 1950 damage was extensive with about 90% of the fir killed along the coast and decreasing to about 60% inland. The infested stands were mainly mature, composed of 80% balsam fir and 20% white spruce. Sheppard is quoted to have estimated that a total of about 117 km^2 (45 sq. miles) of balsam fir forest was severely defoliated, and that about 964 000 m^3 (400,000 cords) of balsam fir trees were dead or dying on the Northern Peninsula (Reeks, Carroll and Sheppard 1949; Reeks, Forbes and Cuming 1949). Most of the looper larvae collected in the latter part of the season in 1950 between Bonne Bay and Hawkes Bay were either dead or diseased (Sheppard 1950).

At Deer Arm an area of at least 5 km^2 (2 sq. miles) was reported to be "heavily attacked" in 1948 (Reeks et al. 1948). A neighbouring small infestation at Lomond covered about 3 km^2 (1 sq. mile) and 10% of the trees over this area were completely defoliated, and were expected to die. At Bonne Bay the first infestation probably started in 1946 and by 1949 it covered about 3 km^2 (1 sq. mile) (Reeks, Carroll and Sheppard 1949). Most of these infestations near Bonne Bay were restricted to poor quality balsam fir stands growing on steep slopes along the shore (Reeks, Carroll and Sheppard 1949).

Other infestations were known to occur along the coast at Portland Creek, River of Ponds, Bustard's Cove, Castor River and St. Margaret's Bay where severe damage has been reported (Sheppard 1950). The infestation covering several km^2 at Bustard's Cove was first reported in 1949 by a party of Swedish and Finnish entomologists and botanists who stated that dead and dying trees were common (Reeks, Carroll and Sheppard 1949). A new infestation covering approximately 10 km^2 (4 sq. miles) was reported in 1950 from Shoal Point (Reeks et al. 1950).

The infestations in the St. John Bay area terminated in 1952 and caused extensive damage. "The dead trees extend from Castor River to the Highlands of St. John, varying from one to four miles (1.6-6.5 km) in width. Another area of dead balsam fir covering about 1 square mile (2.6 km^2) occurs at the southern end of Ten Mile Lake" (Carroll and Parrott 1952).

In 1952 an infestation was discovered near Bowater's logging road about 56 km (35 miles) west of the Hare Bay Depot (Figure 5) in an overmature (120 to 140 years old) balsam fir stand of an undetermined size. About 20% of the current growth was defoliated indicating that the infestation was probably new. A blackheaded budworm (Acleris variana (Fernald)) infestation was also reported from this area in 1950 and 1951 (Carroll and Parrott 1952).

In 1953 an aerial survey revealed two neighboring infestations; one near Leg Pond and Middle Gulch Brook, covering about 13 km^2 (5 sq. miles), and the other at Round Lake. The latter covered an area of about 78 km^2 (30 sq. miles) extending from the St. Genevieve Watershed into the Hare Bay Watershed. The main part of this infestation was between 6 and 8 km (4 and 5 miles) wide and 10 to 13 km (6 to 8 miles) long covering about 84 km^2 (32 sq. miles), and was probably several years old. Surrounding this were several smaller, isolated infested areas, varying from a few hectares up to 3 km^2 (1 sq. mile) where balsam fir was defoliated (Carroll and Parrott 1953; Stillwell and Davidson 1953).

During ground surveys in July 1953 defoliation at the Round Lake infestation was estimated at 50% of the current growth and 30% of the old growth. Larval numbers averaged 470 per tree sample in the heavy infestation and 22 per tree sample in the light infestation (Carroll and Parrott 1953). However, when an aerial survey of this infestation was made in early September, defoliation appeared complete over most of the area. Defoliation was most severe in areas where balsam fir comprised about 90% of the stand. Defoliation at the periphery of the infestation, was lighter, where the balsam fir content of the stands was about 65% (Carroll and Parrott 1953). The area of damage in 1954 expanded to just over 96 km^2 (37 sq. miles) of which about 73 km^2 (28 sq. miles) contained merchantable stands (Parrott 1955). Based on past average yield of 48.2 m^3/ha (20.0 cords per acre) from the Northern Peninsula, the infested area represents about 867 600 m^3 (360,000 cords) of pulpwood. Balsam fir mortality in the greater part of this infestation ranged from 75% to 100%, and it has been estimated that 723 000 m^3 (300,000 cords) has been killed (Carroll 1956). In 1955 the infestation subsided substantially and only about 5 km^2 (2 sq. miles) were infested and defoliation was estimated at about 25% of the new shoots (Carroll and Parrott 1955). Larval mortality from disease was not observed at this infestation, and the cause of the decline of looper population is unknown.

Various Smaller Infestations

Several smaller, scattered infestations also occurred in eastern, central and western Newfoundland during this outbreak.

In eastern Newfoundland moderate to severe infestations were reported in 1947 at Deer Pond and Kepenkeck Lake near Terra Nova (Reeks et al. 1947). The infestation near Terra Nova collapsed in 1948 as no defoliation was observed from the air.

In central Newfoundland moderate to severe defoliation was reported at Gambo Pond, Hunt's Cove (Gander Lake) in 1947 (Reeks et al. 1947). At Hunt's Cove the infestation continued in 1948 but subsided in 1949 (Reeks, Forbes and Cuming 1949).

In 1949 a new infestation, near Red Indian Lake, was reported which covered about 2 km^2 (less than 1 sq. mile) in a pure even-aged balsam fir stand. About 50% to 75% of the new foliage was damaged (Reeks, Carroll and Sheppard 1949). This infestation terminated in 1950 without causing any tree mortality (Carroll and Parrott 1954; Carroll 1956).

In western Newfoundland three small, moderate to severe infestations were reported in 1947; on Glover Island (Grand Lake), Tompkins and Kelley's Landing (Reeks et al. 1947). The infestations at Tompkins and Kelley's Landing collapsed in 1951. The cause of the collapse of these two infestations is unknown; the fate of the other infestation has not been recorded.

In 1949 three new infestations were reported in western Newfoundland; near Gull Pond, at Spruce Brook and George's Lake.

The infestation along the shore of Gull Pond was about 3 km (2 miles) long and defoliation was severe in most of the stands, except the light defoliation of black spruce where this species occurred in equal proportions with balsam fir. This infestation collapsed in 1955 (Carroll 1956).

The infestation at Spruce Brook covered about 5 to 8 km^2 (2 to 3 sq. miles) of even-aged balsam fir forest, about 60 years old. The infestation increased in 1950 and covered about 10 km^2 (4 sq. miles), and 50% of the new shoots and 25% of the old growth were defoliated. No tree mortality occurred and defoliation in 1951 was negligible. The decline of looper populations was attributed to an undetermined disease and to parasites (Carroll 1956).

The infestation at George's Lake covered about 2 to 5 km^2 (1 or 2 sq. miles). Damage was more severe here, and in 1950 defoliation averaged 90%, and about 65% of the merchantable balsam fir trees were killed. The infestation terminated in 1951 and natural control factors, mainly diseases and parasites were responsible for the decline. In 1950 an undetermined disease killed about 70% of the larvae and pupae collected, and about 30% of the insects surviving the disease were parasitized (Reeks et al. 1950; Carroll 1956). Moderate to severe defoliation was recorded in the Anguille Mountains in 1950 but the infestation collapsed in 1951. The cause of the collapse of this infestation was unknown (Reeks and Carroll 1951).

Several shipments of Winthemia occidentis Reinh., a dipterous parasite, were introduced from British Columbia and released at various points in western and central Newfoundland between 1949 and 1951 (Carroll 1956). However, this species did not contribute significantly to looper

mortality, because almost all the parasites reared in 1950 and 1951 were Hymenoptera (Carroll 1956). In addition, high pupal parasitism by an undetermined, probably by a hymenopterous, species was reported from the Grand Falls and Fortune Bay districts in 1948, one year before the introduction started (Reeks et al. 1948).

1959 - 1964

Population levels were low between 1954 and 1957 but numbers of looper larvae in the samples increased from a total of 23 larvae collected in 1957 to a total of 116 collected in 1958 (Carroll and Parrott 1958). Larval numbers further increased in 1959 in eastern and central Newfoundland, and light defoliation was reported near Hunt's Cove, Gander Lake (Carroll and Parrott 1959). The infestation at Hunt's Cove covered approximately 2 km^2 (1 sq. mile) and most of the stand was cut for pulpwood the following year. The infestation apparently subsided as only a few larvae were found in the stands outside the perimeter of the logged area in 1960. The highest number of larvae in 1960, 15 per tree sample, was recorded at Bunyan's Cove near Clarenville. Another infestation, covering approximately 1 km^2 (0.5 sq. mile) was reported in 1961 between Journois and Barry brooks (St. Georges District) in western Newfoundland. Defoliation of current shoots ranged between 10% and 20%. This infestation was also terminated by cutting the infested stand (Carroll and Parrott 1961).

Light defoliation was reported at several locations in 1961 in the Hawkes Bay-Portland Creek area. These infestations intensified in 1962 when they covered about 65 km^2 (25 sq. miles) of merchantable balsam fir forest. Defoliation ranged from 30% to 60% of the current growth throughout the infestation. All infestations occurred west of the Long Range Mountains and south of Hawkes Bay. The largest infestation covered about 52 km^2 (20 sq. miles) between Brian's and Flat ponds, located about 16 km (10 miles) southeast of River of Ponds Lake (Parrott et al. 1963). Smaller infestations occurred near Hawkes Bay, approximately 10 km^2 (4 sq. miles) and near River of Ponds Lake about 40 hectares (100 acres) in size. The infestations on the Northern Peninsula had terminated by 1963.

Small infestations causing severe defoliation were reported in 1961 in western Newfoundland; near McIver's (Bay of Islands), between Little Bonne Bay Pond and the Eastern Arm of Bonne Bay, and near Ming's Bight and Middle Arm on the Baie Verte Peninsula (Figure 6).

The infestation at McIver's covered about 5 km^2 (2 sq. miles) with about 60% current defoliation of mature balsam fir. Many dead larvae were found at this infestation in June 1962 suggesting the presence of some undetermined disease (Parrott et al. 1963).

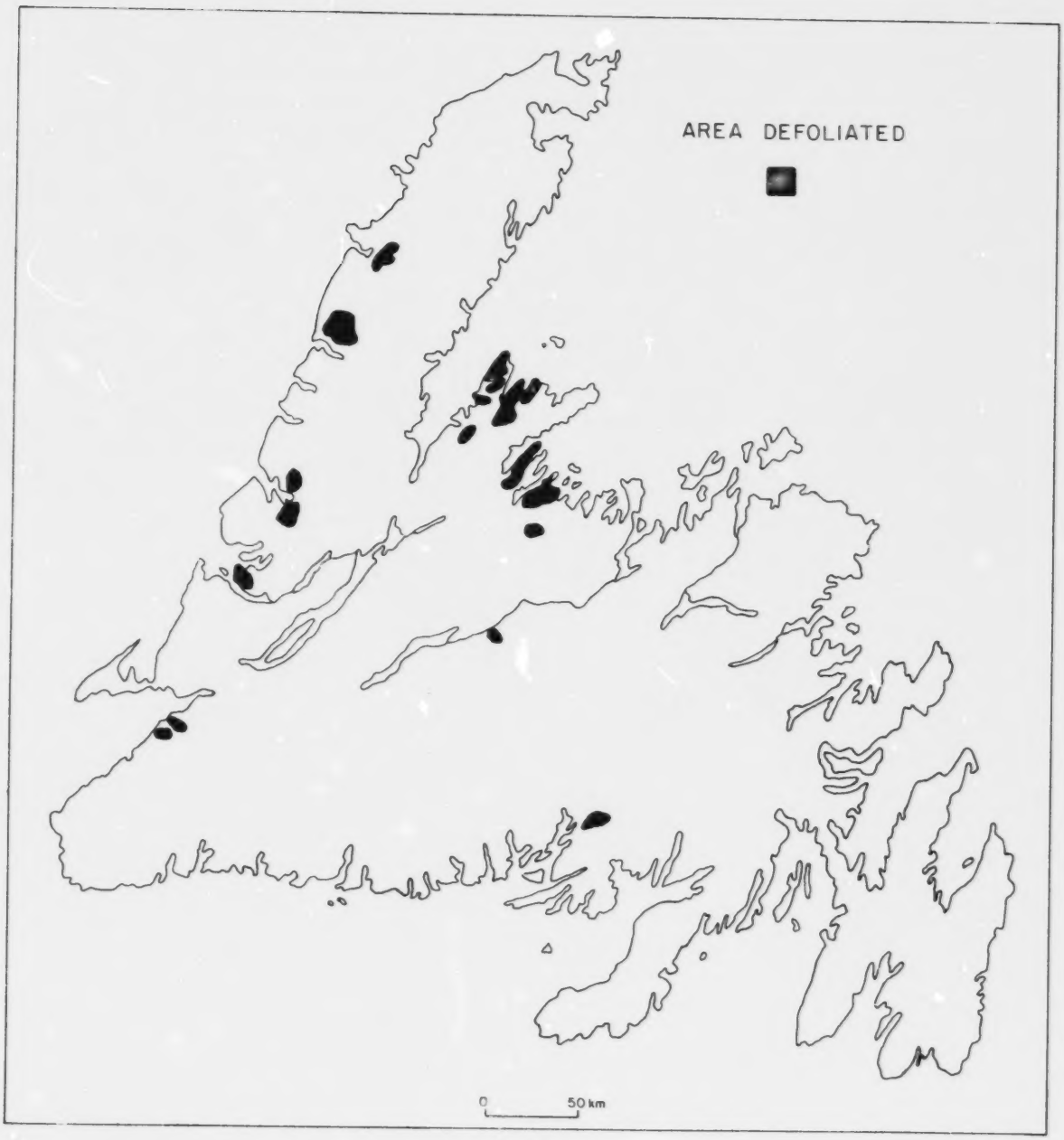

Fig. 6. Areas defoliated by the eastern hemlock looper during the 1959-1964 outbreak.

The infestation between Little Bonne Bay Pond and the Eastern Arm of Bonne Bay was reported in 1961 where 50% to 75% of the current growth was defoliated over about 16 km^2 (6 sq. miles) (Parrott and Clarke 1962). Two other infestations, 8-10 km^2 (3-4 sq. miles) each, one near Big Bonne Bay Pond, another near Little Bonne Bay Pond were discovered in 1962 with 20 to 40% of the current growth defoliated (Parrott et al. 1963). The infestations at Bonne Bay Ponds terminated in 1963 without appreciable tree mortality.

The infestation near Ming's Bight and Middle Arm on the Baie Verte Peninsula was about three years old in 1961, and covered from 13 to 21 km^2 (5 to 8 sq. miles) of balsam fir forest. In 1961 between 60% to 70% of the trees were completely defoliated. Two smaller infestations were also recorded near Middle Arm, one measuring about 2.5 km^2 (1 sq. mile) and the other 5 km^2 (2 sq. miles) (Carroll and Parrott 1961). In 1962 the infestation increased in size between Middle Arm and Ming's Bight and covered a total area of about 78 km^2 (30 sq. miles). About 60% of the affected stands were merchantable, the rest had unmerchantable stunted, coastal trees (Carroll and Parrott 1962). In 1963 the outbreak substantially decreased on the Baie Verte Peninsula and only five small localized infestations, ranging from 3 to 10 hectares (8 to 25 acres) were recorded; in the rest of the infested stands on the Baie Verte Peninsula almost all of the balsam fir trees were killed (Carroll and Parrott 1963). The infestations on the Baie Verte Peninsula collapsed in 1963 and no defoliation was seen during an aerial survey in 1964 (Warren and Parrott 1964, Parrott et al. 1965).

A small infestation, about 0.5 hectare (1 acre) was reported in 1962 on an island in Sandy Lake near Badger in central Newfoundland in a pole size stand of balsam fir. Defoliation ranged from 70% to 80% of the current growth in 1962 (Carroll and Parrott 1962). The following year, in 1963, defoliation was estimated at 90% of the current growth and the infestation was sprayed from the ground with DDT (50% DDT, 1.6 kg in 450 ℓ, 3 lb. in 100 gallons) (Parrott et al. 1964). Most of the larvae were killed and there was no visible defoliation in 1964.

In 1962 and 1963 an infestation occurred at Swanger's Cove, Bay d'Espoir in the same general area where the looper caused severe defoliation and some tree mortality in 1946 and 1947. The infestation was in immature balsam fir stands and covered about 10 hectares (25 acres). The stand sustained between 50 to 80% defoliation of the current growth caused by looper, in association with tussock moth and blackheaded budworm which were also present (Carroll and Parrott 1962). The following year defoliation was only light in the area and an aerial survey in the fall of 1964 showed no defoliation indicating that the infestation had terminated.

Almost complete mortality of the infested stands occurred in the infestations reported from the Northern and Baie Verte peninsulas in 1961 and 1962. Most of the stands infested in the Humber and St. George's Districts in 1960 and 1961 have been salvaged, as well as the infested stand at Hunt's Cove, and approximately 4 820 m^3 (2,000 cords) of balsam fir and white spruce in the McIver's area.

1966 - 1972

This outbreak developed rather suddenly; a total of only 8 looper larvae were found in all the samples collected in 1964 and all in eastern Newfoundland (Warren and Parrott 1964). Although looper numbers remained low across the Island in 1965, there was a general increase in the geographic distribution of samples containing looper larvae. A few larvae were collected from balsam fir, black spruce and white spruce between Grand Lake and Little Grand Lake in western Newfoundland, and near Grand Falls in central Newfoundland. Looper numbers increased in the samples from eastern Newfoundland; in Terra Nova National Park, Markland, Salmonier Nursery and near Pinsent's Ridge (Terra Nova). Ground surveys showed less than 5% defoliation of the current growth in the infested stands in eastern and western Newfoundland and none in the central part of the Island (Parrott et al. 1965).

There was a general increase both in the distribution and in the number of looper larvae collected across the Island in 1966 indicating the beginning of a new outbreak. The largest population increase occurred in the Bottom Brook and Crabbes River watershed area where larval numbers averaged 9 per tree sample. Fewer than 9 larvae per tree sample were collected between Little Grand and Grand lakes in the Gallants area. Larval numbers averaged less than 1 larva per tree sample on white spruce and balsam fir on the Northern Peninsula in the Portland Creek and Parsons Pond areas. Aerial surveys in the fall showed light to moderate defoliation in the Bottom Brook and Crabbes River areas covering about 120 hectares (300 acres) (Figure 7). Most of these stands were severely damaged previously by the balsam woolly aphid. Large moth flights were observed during ground surveys in the area, in August and September (Parrott et al. 1967).

The warm, dry summer throughout the Province in 1966 favored looper development and weather in the late summer was also favorable for mating and egg laying by the females. Population levels reached epidemic proportions in 1967 and infestations occurred throughout the Island covering about 48 780 hectares (120,550 acres) (Figure 7, Table 2). Most of the infestation, approximately 45 730 hectares (113,000 acres) occurred in western Newfoundland (Table 2) including 18 200 hectares (15,000 acres) on which the new growth was completely defoliated. Severe defoliation occurred in the Highland River, Crabbes River, Robinsons and Fishels River, Flat Bay Brook, Southwest Brook watersheds and Serpentine Lake areas. Moderate defoliation occurred in smaller areas west of North Branch in the Codroy Valley.

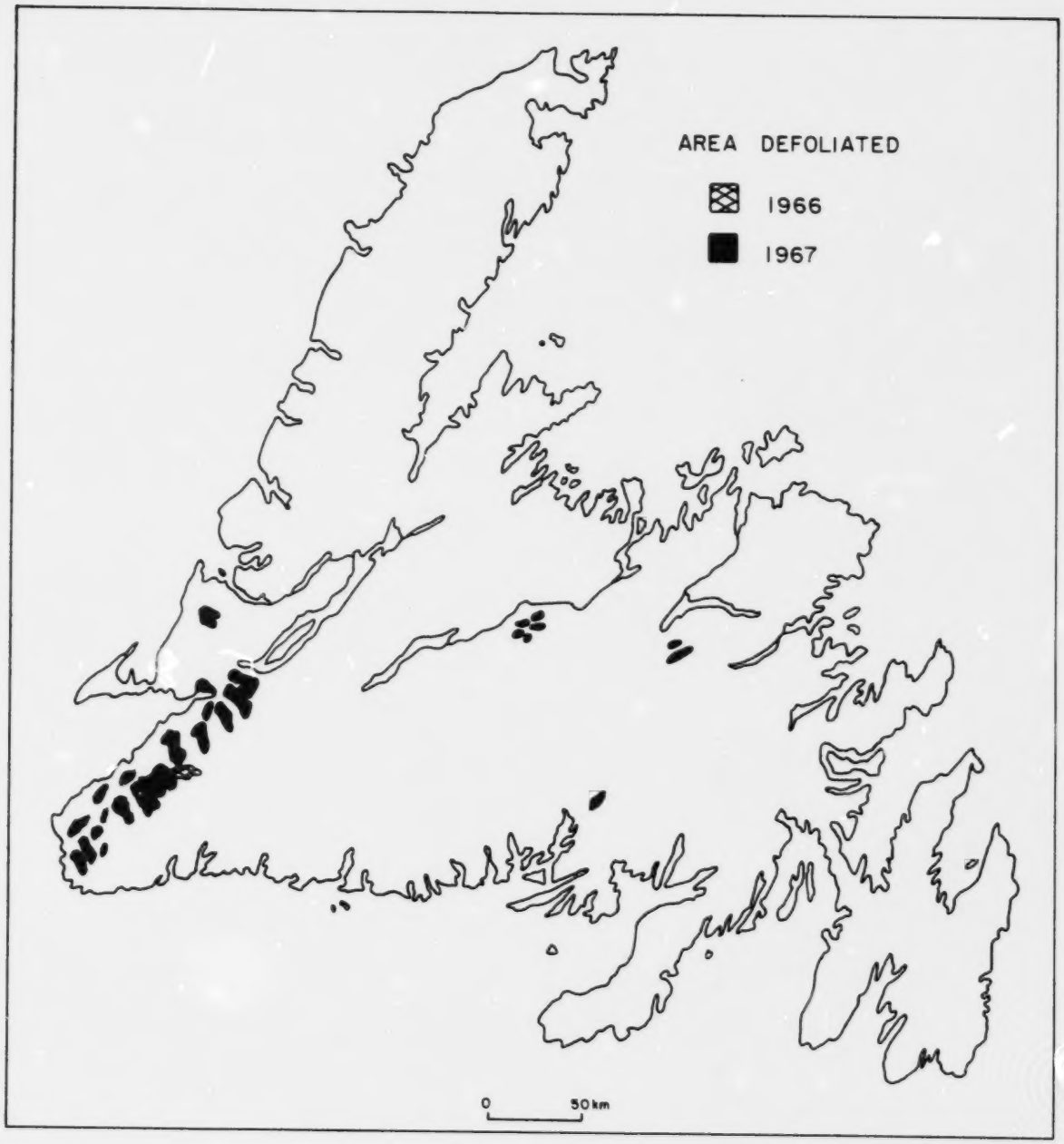

Fig. 7. Areas defoliated by the eastern hemlock looper in 1966 and 1967.

Table 2. Intensity and extent of hemlock looper defoliation in the productive forest areas by geographic regions during the 1966-72 outbreak.*

Area defoliated	1966	1967	1968	1969	1970	1971	1972	Total
WESTERN NEWFOUNDLAND								
Light - acres	-	2,430	36,020	81,580	24,940	11,650	-	156,620
hectares	-	983	14 577	33 014	10 093	4 715	-	63 382
Moderate - acres	300	2,440	34,300	83,280	24,090	14,960	-	159,370
hectares	121	987	13 880	33 702	9 749	6 054	-	64 493
Severe - acres	-	107,840	99,130	65,660	49,010	33,200	-	354,840
hectares	-	43 641	40 117	26 572	19 834	13 436	-	143 600
Total - acres	300	112,710	169,450	230,520	98,040	59,810	-	670,830
hectares	121	45 611	68 574	93 288	39 676	24 205	-	271 475
CENTRAL NEWFOUNDLAND								
Light - acres	-	2,170	95,350	66,110	56,320	650	-	220,600
hectares	-	878	38 587	26 754	22 792	263	-	89 274
Moderate - acres	-	2,170	35,690	116,040	94,650	650	500	249,700
hectares	-	878	14 443	46 960	38 304	263	200	101 048
Severe - acres	-	-	35,930	183,780	113,520	-	-	333,230
hectares	-	-	14 540	74 373	45 940	-	-	134 853
Total - acres	-	4,340	166,970	365,930	264,490	1,300	500	803,530
hectares	-	1 756	67 570	148 087	107 036	526	200	325 175

Cont'd ...

Table 2 - Concluded

Area defoliated	1966	1967	1968	1969	1970	1971	1972	Total
				EASTERN NEWFOUNDLAND				
Light - acres	-	3,500	78,200	22,770	-	-	2,500	106,970
hectares	-	1 416	31 646	9 215	-	-	1 000	43 277
Moderate - acres	-	-	55,110	78,660	-	-	-	133,770
hectares	-	-	22 302	31 833	-	-	-	54 135
Severe - acres	-	-	48,920	17,860	-	-	-	66,780
hectares	-	-	19 797	7 228	-	-	-	27 025
Total - acres	-	3,500	182,230	119,290	-	-	2,500	307,520
hectares	-	1 416	73 745	48 276	-	-	1 000	124 437
Total Area Defoliated								
- acres	300	120,550	518,650	715,740	362,530	61,110	2,500	1,781,880
- hectares	121	48 783	209 889	289 651	146 712	24 731	1 000	721 087

*Infested areas recorded by years show only the increase in area for that year.

Smaller and less severe infestations were found at four separate locations in central Newfoundland: Pamehac Brook (near Badger), Greenwood Brook (south of Glenwood along the northwest Gander River), Caribou Pond (Southwest Gander River), and at Conne River (in the Bay d'Espoir area). These four infestations covered a total of about 3 040 hectares (7,500 acres). An infestation between Goobies and Deer Arm, Trinity Bay in eastern Newfoundland covered about 1 420 hectares (3,500 acres) (Clarke et al. 1968).

An estimated 2 410 000 m^3 (1,000,000 cords) of merchantable wood was infested, and 60% of this was killed or severely damaged as a result of 1 or 2 years of severe looper attack (Warren et al. 1967).

Surveys in the fall of 1967 showed heavy moth flights in all defoliated stands and looper adults were numerous in the adjacent undamaged stands indicating the high probability of a further expansion of the outbreak in 1968. The possibility of this extension of the outbreak and subsequent tree mortality prompted the Provincial Department of Mines and Agriculture, assisted by the Forest Industries and the Federal Government, to undertake a chemical control operation in 1968 and 1969 to minimize damage. Details of the spray operation were reported by Otvos et al. (1971) and only the highlights are reviewed.

Chemical Control Operations Against the Hemlock Looper

In mid-May 1968 the Provincial Government authorized the first aerial spraying against any insect in the Province. In 1968, 174 420 hectares (431,000 acres) were treated. Fenitrothion and phosphamidon were used in western Newfoundland; phosphamidon near major water systems, because of its lower toxicity to aquatic life, and fenitrothion in other areas; and only fenitrothion was used in central Newfoundland (Otvos et al. 1971). All infested areas were treated with two applications of insecticide at 0.15 kg/ha (2 oz/acre) at 6 to 8-day intervals with two exceptions; one in western, the other in central Newfoundland. Infestations at these two locations received one application of 0.3 kg/ha (4 oz/acre). This increased dosage was used because light to moderate defoliation had already occurred in these stands, and because looper larvae were in the more destructive late instars which are more resistant to the chemical.

Larval mortality averaged 86%, the highest reduction, 98% occurred in stands treated with phosphamidon compared to 87% in stands treated with fenitrothion. Two treatments at 0.15 kg/ha (2 oz/acre) each were more effective than the single treatment at 0.3 kg/ha (4 oz/acre), which gave about 62% mortality. The spray operation was effective, it reduced the size of the infestation and the intensity of damage in the treated areas. Aerial surveys in the fall of 1968 however, showed severe defoliation of fir stands throughout the Island (Figure 8). This continued persistence of severe defoliation resulted in another spraying operation in 1969 when a total of 831 600 hectares (2,054,900 acres)

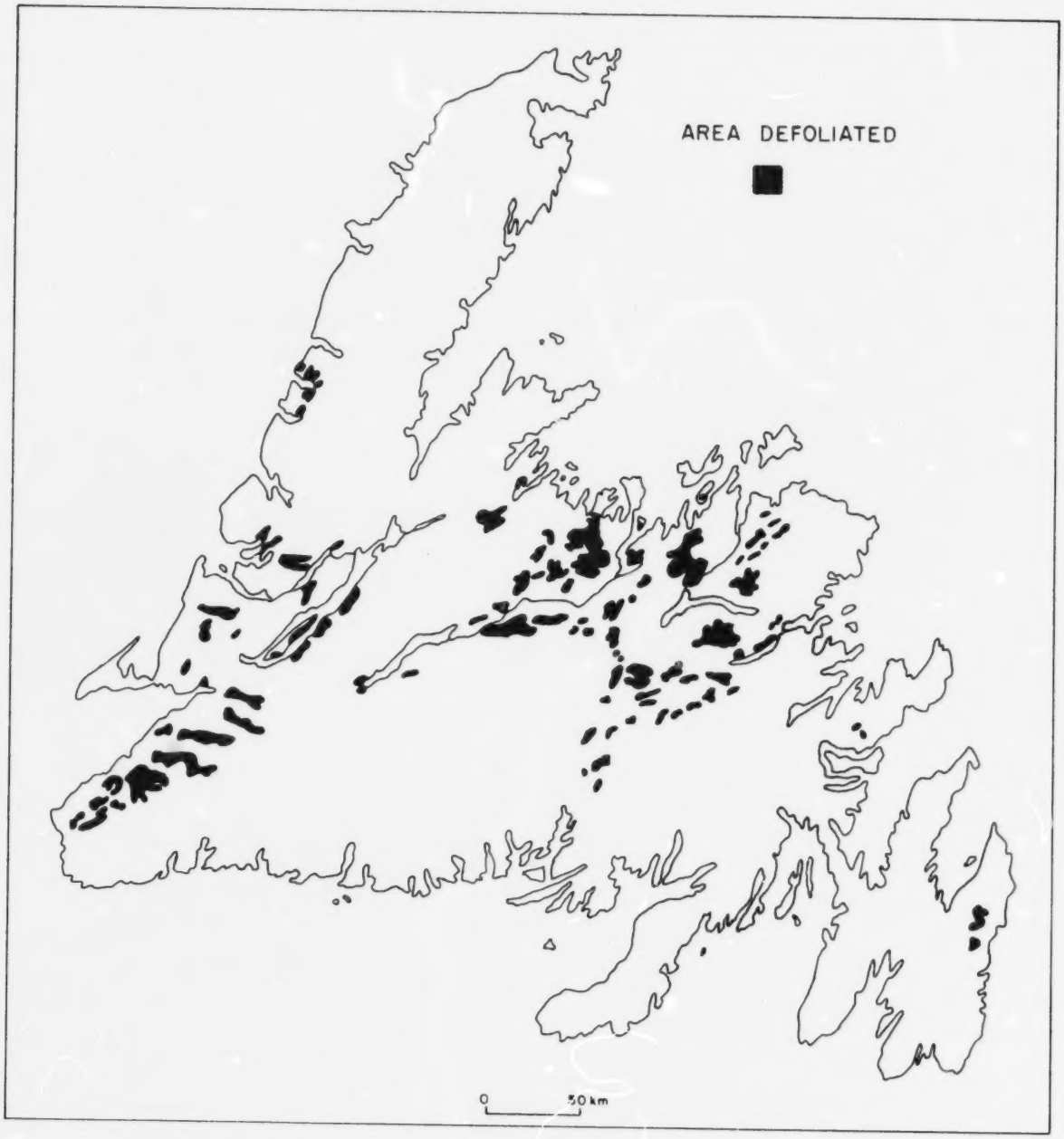

Fig. 8. Areas defoliated by the eastern hemlock looper in 1968.

were treated. The same two insecticides, fenitrothion and phosphamidon, were used and essentially in the same way as in 1968. Post-spray larval sampling showed an average larval mortality of 80% in stands treated with phosphamidon and 94% in stands treated with fenitrothion (Otvos et al. 1971). The outbreak peaked in 1969 when 289 650 hectares (715,740 acres) were defoliated (Table 2, Figure 9) of which 175 230 hectares (433,000 acres) were in the treated areas and the rest in unsprayed stands. The chemical spray operation in 1968 and 1969 is credited with saving an estimated 24 100 000 m^3 (10,000,000 cords) of wood.

The outbreak decreased in 1970 when about 146 710 hectares (362,530 acres) were defoliated (Table 2, Figure 10). Most of the defoliation occurred in stands near Grand Falls in central Newfoundland, while the remaining defoliation was near Portland Creek, Adies Pond and Grand Lake in western Newfoundland (Clarke et al. 1971). The major part of the outbreak collapsed in 1971 and only about 24 730 hectares (61,110 acres) were defoliated (Table 2, Figure 11). The largest infestation occurred in the Baie Verte-Birchy Lake area where light to severe defoliation was recorded over 18 620 hectares (46,000 acres). On the Northern Peninsula moderate to severe defoliation was observed in about 4 450 hectares (11,000 acres) at Portland Creek, and light to moderate defoliation near Ten Mile Lake in a 530 hectares (1,300 acres) area. In central Newfoundland light to moderate defoliation was recorded over about 530 hectares (1,300 acres) (Table 2) area near Lake Ambrose (Clarke et. al. 1972). Only about 530 hectares (1,300 acres) near Ten Mile Lake and about 405 hectares (1,000 acres) in the Baie Verte area were defoliated for the first time in 1971. By 1972 the outbreak collapsed throughout the Island, except for a small area of about 200 hectares (500 acres) near Ming's Bight on the Baie Verte Peninsula, and two new localized infestations in the Salmonier Valley on the Avalon Peninsula (Clarke et al. 1973). Defoliation was moderate at Ming's Bight; part of the stand was cut and the infestation collapsed in 1972. The total area infested in the Salmonier Valley was approximately 1 000 hectares (2,500 acres) and defoliation was light. This infestation also collapsed in 1972.

Damage Caused by the Hemlock Looper

Data compiled during the 1966-72 outbreak show that the eastern hemlock looper defoliated about 721 090 hectares (1,781,880 acres) of productive fir-spruce forest (Tables 2 and 3), including about 300 540 hectares (742,650 acres) in the severe category (Table 3). Tree mortality occurred over 596 190 hectares (1,474,700 acres) containing 110 430 hectares (272,890 acres) of merchantable stands representing 12 021 263 m^3 (4,988,076 cords) (Table 4). Tree mortality continued for a number of years after the outbreak collapsed even though there was no further defoliation (Hudak et al. 1978). This tree mortality, subsequent to the collapse of infestations, represented an estimated 723 000 m^3 (300,000 cords) of wood.

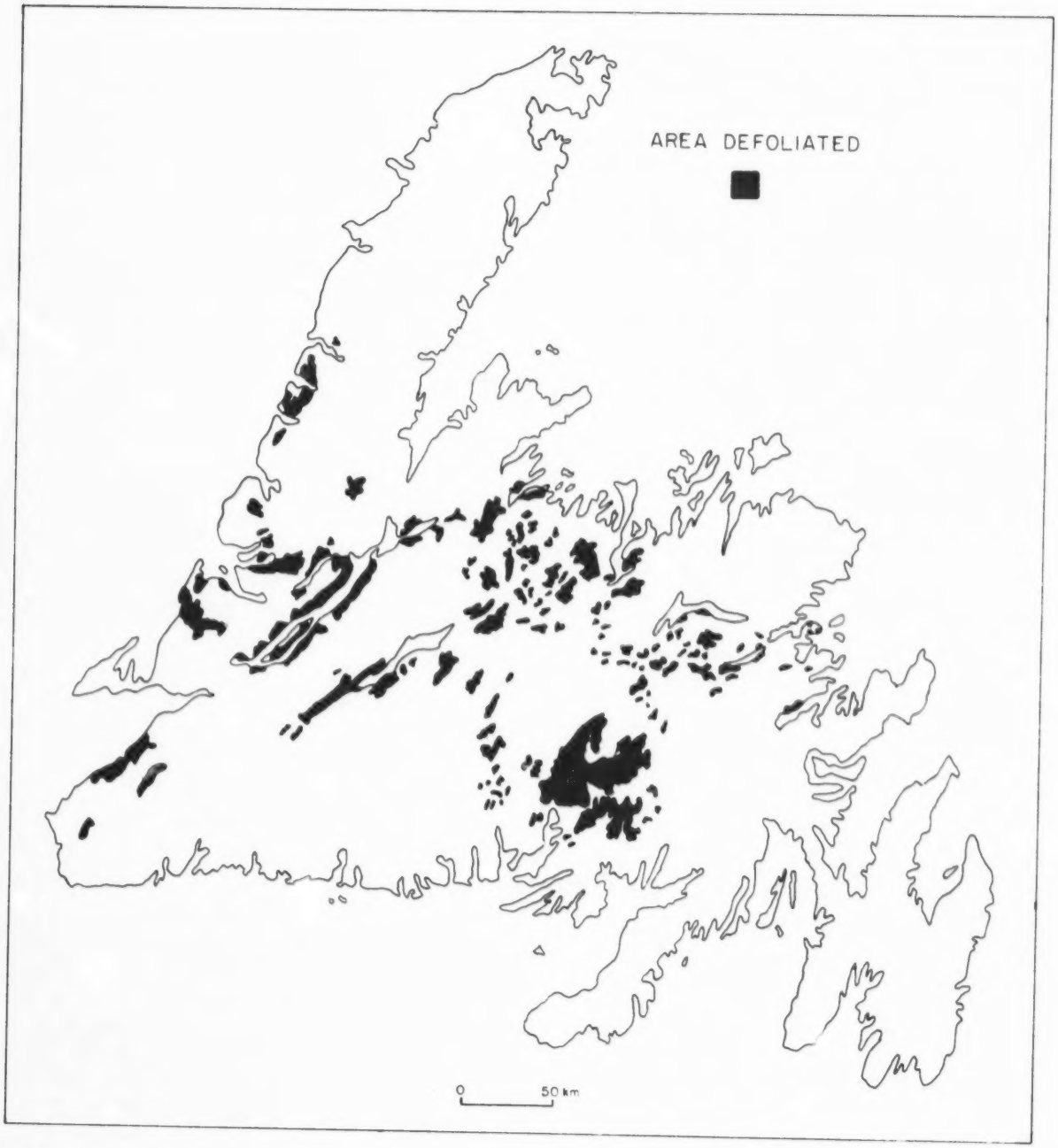

Fig. 9. Areas defoliated by the eastern hemlock looper in 1969.

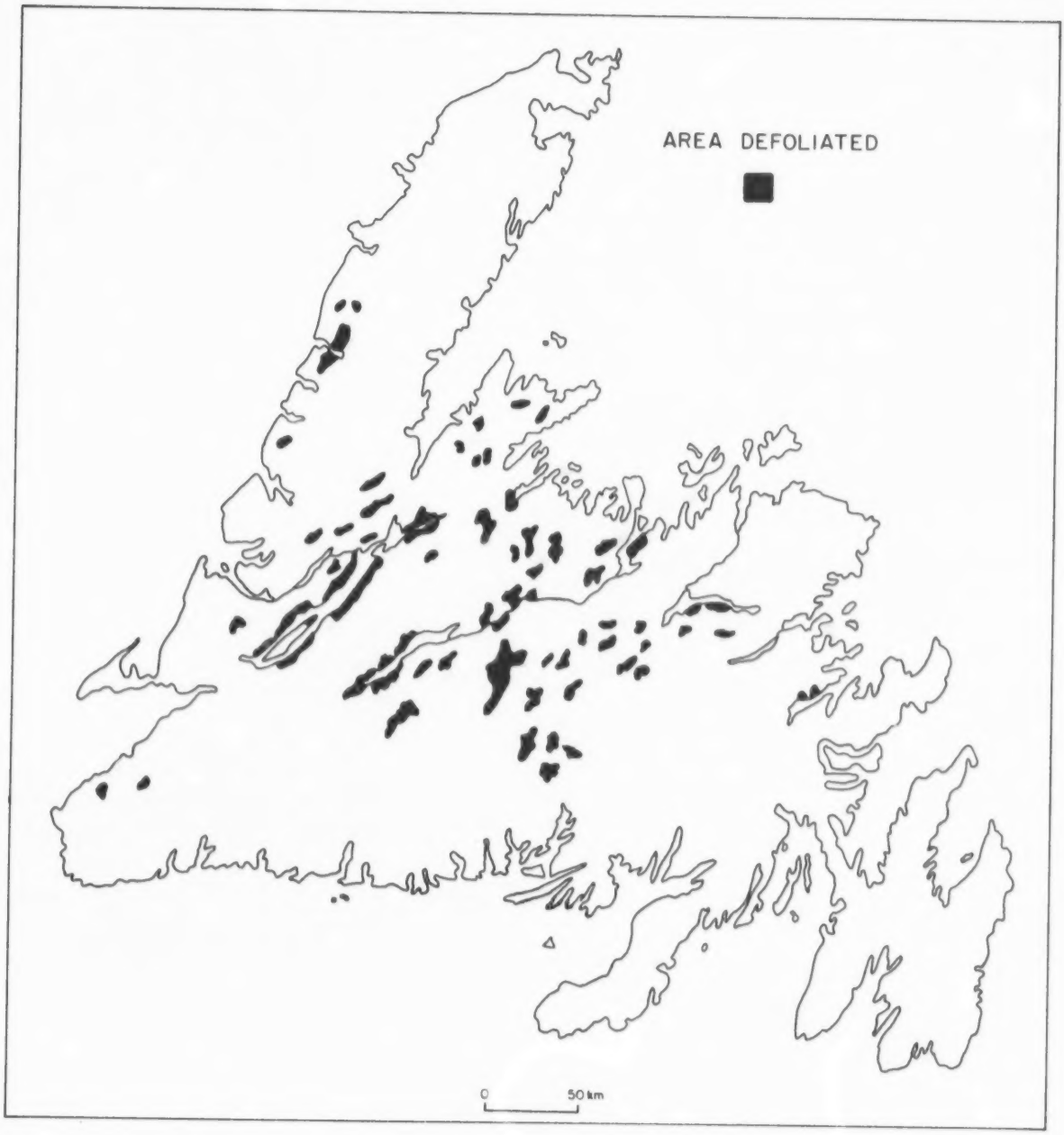

Fig. 10. Areas defoliated by the eastern hemlock looper in 1970.

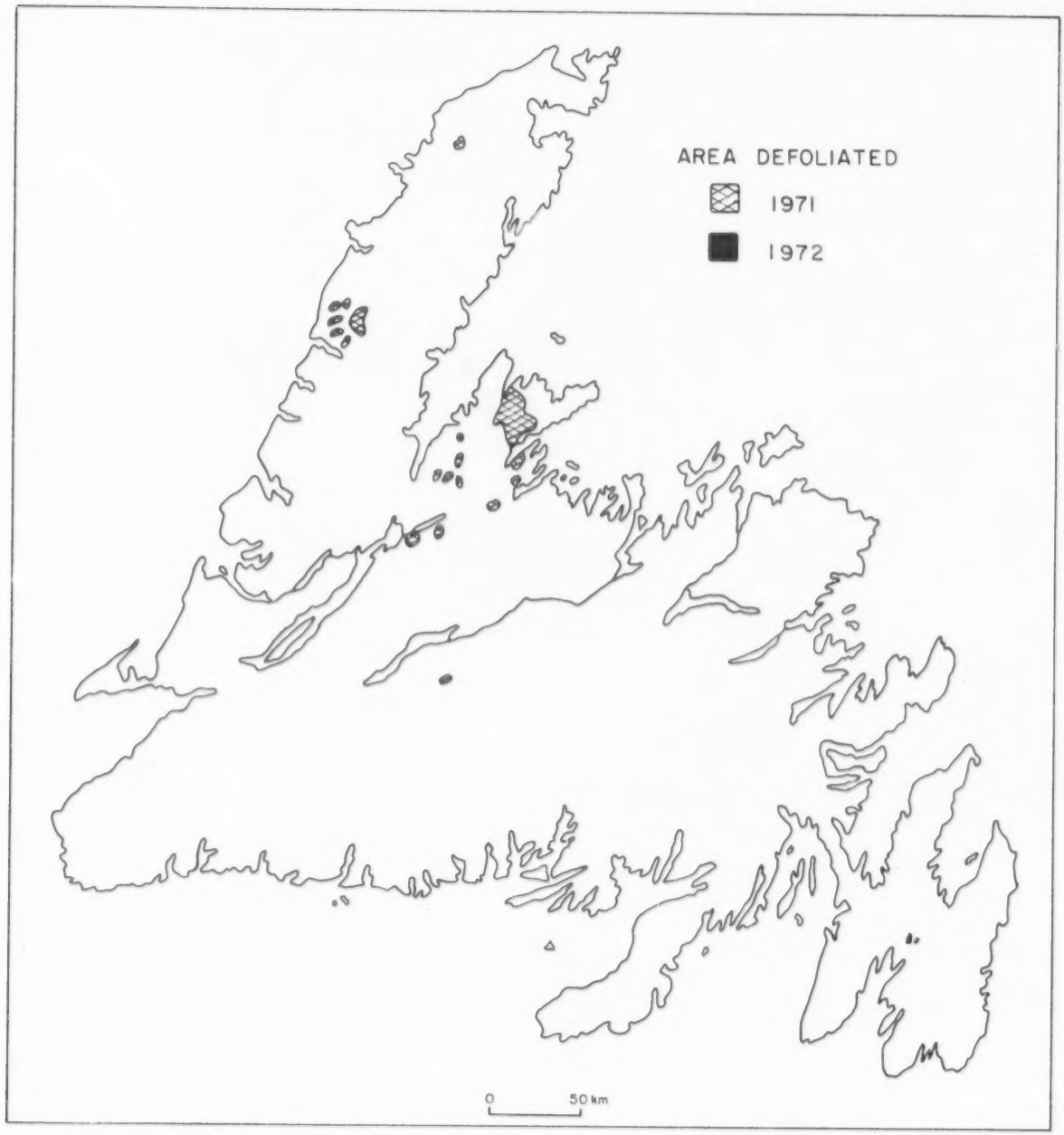

Fig. 11. Areas defoliated by the eastern hemlock looper in 1971 and 1972.

Table 3. Areas of productive forest defoliated by the eastern hemlock looper by inventory regions during the 1966-72 outbreak in Newfoundland.

Inventory region	Defoliation classes					
	Light and moderate		Severe		Total area	
	ac	ha	ac	ha	ac	ha
1	57,150	23 130	36,570	14 800	93,720	37 930
2	251,710	101 860	292,280	118 280	543,990	220 140
3	380,520	153 990	198,310	80 250	578,830	234 240
4	167,160	67 650	57,020	23 080	224,180	90 730
5	150,260	60 810	154,590	62 560	304,850	123 370
6	25,470	10 310	2,410	980	27,880	11 290
7	6,960	2 800	1,470	590	8,430	3 400
Total	1,039,230	420 550	742,560	300 540	1,781,880	721 090

Table 4. Distribution of stands killed by the eastern hemlock looper in the various forest cover types[1] by inventory regions in Newfoundland, 1966-72.

Inventory region		Acres of stands killed					Merchantable wood killed[2]	
		Softwoods S	Soft-Hardwoods SH	Hard-Softwoods HS	Hardwoods H	Total	cords	m^3
1	ac	5,570	1,650	170	330	7,720	117,090	282 190
	ha	2 250	670	70	130	3 120		
2	ac	81,080	25,360	2,160	2,200	110,800	2,099,650	5 060 160
	ha	32 810	10 260	870	890	44 830		
3	ac	42,910	28,040	2,950	1,860	75,760	1,283,720	3 093 760
	ha	17 370	11 350	1 200	750	30 670		
4	ac	25,360	2,460	5,030	730	33,580	662,100	1 595 660
	ha	10 260	1 000	2 040	300	13 590		
5	ac	35,610	5,530	450	400	41,990	789,800	1 903 420
	ha	14 410	2 240	180	160	16 990		
6	ac	1,910	-	-	-	1,910	24,690	59 500
	ha	770	-	-	-	770		
7	ac	950	110	60	20	1,400	11,020	26 560
	ha	390	50	20	10	470		
Total	ac	193,390	63,150	10,820	5,540	272,900	4,988,070	12 021 250
	ha	78 260	25 560	4 380	2 240	110 440		

[1] S = 75-100% softwood by crown closure
SH = 50-74% softwood by crown closure
HS = 25-49% softwood by crown closure
H = 0-24% softwood by crown closure

[2] Both cords and m^3 killed include merchantable volume of all species in affected stands.

Approximately 77% of the total area defoliated was in the moderate and severe defoliation classes in western Newfoundland, 74% in central and 66% in eastern Newfoundland. Sixty-one percent of the mortality (by area) was in western, 13% in central and 26% in eastern Newfoundland. About 87% of the productive forest area in western Newfoundland was mature and overmature in which balsam fir represented over 65% of the gross merchantable volume (Anon. 1974). In central and eastern Newfoundland 73% and 23% of the stands were mature and overmature and 35% and 55% of the gross merchantable volume was composed of balsam fir in these respective regions (Anon. 1974).

Considerable variation in the progress of tree mortality in the defoliated stands was evident. Most of the mortality occurred among stands defoliated 75% or more, and about 25% of the trees were killed in stands defoliated only 50%, and about 10% tree mortality occurred in stands with 30% average defoliation (Hudak et al. 1978).

Salvage operations were initiated by the forest industry and the Provincial Forest Service in 1968 to harvest dead and severely damaged stands. Salvage continued until 1971 and a total of 2 000 300 m^3 (830,000 cords) were harvested (Table 5). This is less than 17% of the total amount of wood killed by the hemlock looper. It may be of interest to note that during the same period a total of 9 364 600 m^3 (3,885,740 cords) were harvested in Newfoundland (Table 5) about 75% of which was uninfested by the looper.

Natural Control Agents

Before 1950 no special studies were conducted on natural control agents and only cursory observations were made during sampling. Between 1950 and 1951 a study was conducted on the biology and history of the hemlock looper in Newfoundland which also discussed the natural control agents briefly (Carroll 1956). However, these factors were studied more intensively during the 1966-72 outbreak (Otvos 1973), and the four most important factors, i.e., weather, predation, parasitism and pathogens will be discussed below.

Weather - Temperature and precipitation differences from the long term normal, during the larval and pupal stage of the insect were correlated with changes in looper numbers during the 1966-1972 outbreak. The data showed that above normal temperatures occurred for the first 2 years of the outbreak with below normal precipitation, precipitation was above normal with below normal temperatures for 3 years during the decline of the outbreak.

Table 5. Evaluation of salvage operation conducted during the period from 1968 to 1971 to minimize losses caused by the eastern hemlock looper.

	Units	Bowater	Price	Crown	Total
Volume killed	cords	-	-	-	4,988,076
	m^3	-	-	-	12 021 263
Volume salvaged	cords	269,129	455,924	93,633	830,485
	m^3	648 601	1 098 777	225 656	2 001 469
Net loss	cords	-	-	-	4,157,585
	m^3	-	-	-	10 019 780
Total volume harvested	cords	1,738,140	1,499,780	647,820	3,885,740
	m^3	4 188 917	3 614 470	1 561 246	9 364 633
% salvage of total harvest		15.1	30.4	14.5	24.4
% salvage of total killed		-	-	-	16.6

Data in Table 5 are taken from Table 27 from the "Report of the Committee on Forest Improvement and Protection" presented to the Federal-Provincial Task Force on Forestry. Volume figures were converted from cunits to cords. 1 cunit = approximately 1.18 cords; 1 cord = 2.41 m^3.

When the same relationship was examined during the previous two outbreaks (1949-1955, 1959-1963) the data showed that an increase in looper numbers to epidemic level was preceded by 2 years of warmer than normal temperatures and less than normal precipitation (Otvos 1977a). It can generally be concluded that looper population increases during warmer and drier than normal years or this increase is preceded by warmer and drier normal years. Conversely, looper populations decline during cooler and wetter than normal years.

A study conducted after the recent outbreak indicated that mortality of overwintering looper eggs was inversely related to the difference between the mean monthly temperature and the normal during the winter (Otvos 1977b). The lethal low temperature for overwintering looper eggs was not determined.

Predators - No attempt was made during the 1966-1972 outbreak to assess the value of invertebrate predators. Only avian predators were studied (Otvos and Taylor 1970, Otvos 1973). Studies conducted between 1969 and 1971 showed that 19 species of birds fed on the hemlock looper. All stages of the looper were preyed upon. Hemlock looper made up 45% of the diet of the birds in 1969, 22% in 1970 and 30% in 1971. Larval numbers averaged 148 per tree beating in 1969, 100 in 1970 and 91 in 1971. The looper population collapsed in the area where the birds were collected in 1971 and no larvae reached the adult stage, but looper larvae and pupae composed 34.5% of the diet of the birds in 1969, 32.2% in 1970, and 29.3% in 1971 suggesting a tendency for predation by birds to decrease with a decrease in looper numbers.

This trend, in conjunction with the relatively high looper content in individual bird gizzards, indicates that birds respond to changes in looper population levels and may add considerably to the combined effect of the biotic agents in reducing looper numbers. However, birds cannot be considered to cause the collapse of a hemlock looper or any other forest insect outbreak alone (Otvos 1979).

Parasites - Parasites had a more significant effect on the course of outbreak than predators. Thirteen species of primary parasites were reared from the looper and parasitism of all stages of the looper increased as the outbreak developed.

Egg parasitism caused by Telenomus sp., was generally low and it averaged 3.9% in 1969, but increased with the age of the outbreak and reached a high of 22.7% in the fifth year when the outbreak was about to

collapse. Parasitism over the 4 years varied from 1.6% to 48.0% between locations. In general, egg parasitism was low, and these parasites cannot be considered to contribute appreciably to the collapse of looper outbreaks. However, they may be of considerable importance in isolated infestations as nearly 50% of the eggs were parasitized at one location in 1971, the year before the infestation collapsed at that location (Otvos 1973).

Larval and pupal parasitism was considerably more important, and was caused by 12 species of parasites. These were four species of tachina flies: Blondelia eufitchiae (Tns.), Madremyia saundersii (Will.), Phryxe pecosensis (Tns.), Winthemia occidentis Rnd., and eight hymenopterous species: Aoplus velox (Cress.), Apechthis ontario (Cress.), Itoplectis conquisitor (Say), Apanteles sp., Phobocampe sp., Zele sp., and an undetermined species of the subtribe Acrolytina and another from the sub-family Porizontinae. Hyperparasitism was rare (Otvos 1973). It may be interesting to note that W. occidentis was introduced against the eastern hemlock looper between 1949 and 1951 (McGugan and Coppel 1962), but it was not recovered until 1969. I. conquisitor was introduced against the blackheaded budworm, Acleris variana Fern., in 1950 and A. ontario was introduced against the spruce budworm in 1947 and 1951, and both have since transferred to the looper.

Parasitism by Diptera generally increased with the age of the outbreak. Combined parasitism by the four Diptera was 13.5% in 1969, and reached a high of 65.8% in 1972. Parasitism by the hymenopterous species was only about 1% during the same period. Parasitism by Diptera varied from a low of 1.2% to a high of 86.9% among the locations sampled (Otvos 1973). It may be interesting to note that an earlier study showed Hymenoptera more important than Diptera; parasitism by the former group was about 30%, while the latter caused only negligible parasitism (Carroll 1956). This change in the importance of the two groups during the two outbreak periods appears to be related to the emergence of W. occidentis as the dominant parasite. This parasite had just been released prior to the investigation in 1950 and 1951; consequently, its effect was negligible compared to the mortality caused by the native parasites. However, during the next 20 years W. occidentis had become the most prevalent parasite of the hemlock looper on the Island.

Pathogens - Only viruses and fungi are known to attack the hemlock looper in Newfoundland.

Studies were conducted in 1969 and 1970 to determine the feasibiliity of applying nuclear polyhedrosis viruses (NPV) as control agents against the eastern hemlock looper. The incidence of NPV virus in natural looper population was low. Cunningham (1970b) found that the nuclear polyhedrosis viruses isolated from eastern and western hemlock

looper and the oak looper were all equally pathogenic to the eastern hemlock looper in Newfoundland. The virus was applied in suspension (equivalent to about 60 virus killed larvae per gallon) using a mist blower. All three viruses had a long incubation period; death was not observed until 20 days after the application of the virus sprays. Larval mortality was estimated at about 20%, in the sprayed area. The results of these tests showed that the rate and dose of the virus suspension spray were excessive making the method economically prohibitive (Cunningham 1970a). The year following spraying, treated areas were checked to determine if transovum transmission of the virus had occurred. No virus infected larvae were found suggesting that the nuclear polyhedrosis virus infecting the hemlock looper is not transmitted from one generation to the next.

Larval collections in 1969 revealed the presence of a disease previously unreported from the Island. The organisms causing the disease were identified as two fungi, Entomophthora sphaerosperma, and a new species, later described as E. egressa (Otvos et al. 1973). These two fungi were recorded from several other locations until the end of the outbreak. The epidemiology of the disease caused by these fungi is poorly understood and, therefore, it is impossible at this time to determine with certainty whether the more prevalent status of the fungal disease in the successive years of the outbreak was the result of the natural spread of the disease, or whether it was the result of the more intensive sampling, or both.

In 1969 fungal infection was noted at McIvers, Serpentine Lake, and South Brook Valley. At Serpentine Lake about 20% of the larvae were infected and at McIvers up to 90%. Estimates of the proportion of infected larvae at South Brook Valley was not made because the area had been treated three times with fenithrothion during a chemical control operation (Otvos et al. 1971), and it was assumed that any larvae that appeared unhealthy or dead were affected by the insecticide. However, subsequent examination of dead larvae from this area showed that nearly 50% contained Entomophthora spp. resting spores. Larval population levels averaged about 35 larvae per tree at all three locations. On rechecking these areas in 1970 no looper larvae were found at Serpentine Lake, only diseased larvae were found at McIvers, and no diseased larvae and only one, apparently healthy, larva at South Brook Valley.

In 1970 fungal infection was found at five other locations: at Frenchman's Cove where about 5% of the late instar larvae were infected; at Boot Brook about 80% of late instar larvae were infected; at the north and south side of Birchy Lake about 15% of the late fourth instar larvae and 20% of the pupae were infected in the western part of the Island. At Joe's Lake, in central Newfoundland, fungal infection was

observed among dead and dying larvae, but percent infection and larval population levels were not estimated at this location. Larval samples averaged 15 per tree beating at Boot Brook, 90 at Frenchman's Cove, and 80 per tree at the north and south side of Birchy Lake.

In 1971 infected larvae were collected at Lake Ambrose, Birchy Lake south and Ming's Bight. Infection was first noted at Lake Ambrose, on July 9. Most of the larvae were in the 2nd instar and about 15% were diseased. Larval numbers averaged 400 per tree sample, however, larval numbers decreased to 25 per tree sample by mid-July when infection was about 90%, and no larvae or pupae were found at the end of the month. The looper infestation at the south side of Birchy Lake averaged 91 larvae per sample tree in late June, by the end of July looper numbers decreased to six per tree and even these were either diseased or parasitized by tachina flies or both. Fungal infection was observed on July 25 at Ming's Bight; larval numbers averaged 250 per tree beating and about 7% were infected. A few 1st instar larvae were collected in this area in June of 1972, and most of the pupae found during subsequent sampling in July and August were parasitized.

The progress of the fungal disease was followed closely by frequent sampling of a looper infestation at the south side of Birchy Lake. The results showed that percent infection increased as the season progressed. Weather appeared to have an important effect on infection. Infection increased to about 13% in the week of July the 11th, a period of almost continuous rainfall. Mean temperature during this week was about 15.6°C (60°F). During the next few days the temperature averaged only about 12.8°C (55°F) and the relative humidity fell to less than 70% and fungal infection declined to about 8%. Following a heavy rainfall on July 20, the temperature rose to a mean of 15.6°C until the end of the sample period and the mean relative humidity exceeded 70%. Percent infection increased rapidly during this time until it reached a high of 74% on the day of the last sampling date August 1. These observations indicate that fungal epizootics may develop best at a mean daily temperature of above 15.6°C, and at a high relative humidity, or when rainfall occurs frequently. During the summer months in Newfoundland relative humidity in the tree crowns usually reaches the dew-point at night, providing suitable conditions for fungus development and sporulation even though rainfall may be minimal.

Results of studies in 1969, 1970 and 1971 indicate that fungal disease was responsible for terminating the outbreak at Serpentine Lake and McIvers in 1969, at Boot Brook and possibly in the Bay d'Espoir area in 1970, and at Lake Ambrose and Birchy Lake in 1971. These results also indicate that the fungi can kill both early as well as later stages of the eastern hemlock looper and may therefore terminate an infestation before defoliation becomes important.

Observations made during the recent study have shown that Entomophthora fungi attacking the eastern hemlock looper larvae in Newfoundland can only be separated from the virus disease, on the basis of external symptoms during the later stages of infection. Otvos (1973) suggested, on the basis of the description of diseased larvae provided by Carroll (1956), that the disease reported during previous outbreaks was very likely caused by these fungi.

CHARACTERISTICS AND PATTERNS OF OUTBREAKS

The history of hemlock looper in Newfoundland indicates that outbreaks are cyclic (Table 1). The period between outbreaks is defined as the time interval between the first years of noticeable defoliation of two consecutive outbreaks. Using this criterion, past records show that the period between outbreaks vary from 7 and 18 years. Outbreaks usually last between 6 and 9 years and reach their peak in 3 to 7 years (Table 1).

Outbreaks usually develop during periods of dry warm weather. Increase in looper numbers to epidemic levels is usually preceded by about 2 years of warmer temperatures from May to August and lower than normal precipitation during this period. Conversely, the decline of looper population in Newfoundland is generally preceded by a period with above normal precipitation and lower than normal temperatures (Otvos 1977a). These and possibly other weather parameters affect looper population directly, and indirectly through affecting biotic control factors of the looper (Otvos 1973).

The descriptions given here show that outbreaks generally begin as small, often widely-scattered, infestations which increase in size and distribution annually under favorable conditions. These scattered infestations often coalesce to form a large irregular outbreak area or groups of infestations forming part of an outbreak, like the ones found on the Northern Peninsula or in western Newfoundland during the 1946-55 outbreak, or the one in the Bay d'Espoir area in 1969. Damage is most severe in overmature and mature balsam fir stands. Nearly 60% of the gross merchantable volume of balsam fir on the Island is located in western Newfoundland including the Northern Peninsula where most of the mortality occurred during the 1966-72 outbreak (Table 2).

Similar results were reported by Watson (1934) and Carroll (1956) who found that high balsam fir content favored development of looper outbreaks in Quebec and Newfoundland, respectively.

Severe defoliation, however, is not entirely restricted to mature balsam fir stands; occasionally severe damage has been recorded in younger stands. However, these younger stands usually contain

scattered groups of overmature trees left after logging or are relatively close to extensive mature stands from which a "spill over" of looper adults occurs. Stand vulnerability to mortality is increased by previous damage caused by other insects or diseases as well as by weakening of the trees caused by adverse site or drought conditions.

Heavily infested stands are readily recognized by the reddish-brown color of the partially-eaten foliage and by the masses of silken threads. The larvae are wasteful feeders, usually consume only a part of the needle before moving on the next needle. This habit plus the fact that the older, more voracious larvae consume older needles results in drastic reduction of the foliage complement of the tree which may result in severe defoliation and tree mortality in 2 or 3 years. Dead trees and dead tops give older outbreaks a characteristic grey appearance.

Wind plays a relatively minor part in the long distance dispersal of the hemlock looper adults, compared to the spruce budworm, although undoubtedly it contributes to the spread of the outbreaks in the direction of the prevailing wind. The prevailing wind generally comes from the southwesterly direction. The spread of the outbreak from this direction could be seen during the last outbreak which started in western Newfoundland. Wind may also contribute to the dispersal of first instar larvae within and among stands at short distances.

Individual infestation usually collapse in about 2-3 years from the time defoliation is noticed. Moist weather cycles during larval development cause a general decline in larval numbers, primarily because such conditions favor an increase in the incidence of entomogenous fungi. Studies conducted on the eastern hemlock looper to date (Otvos 1973) show that under Newfoundland's climatic conditions, two native fungi, Entomophthora sphaerosperma and Entomophthora egressa are the most important biotic factors responsible for the collapse of looper outbreaks, although under certain conditions looper mortality caused by parasitism may also be important. The data collected suggest that fungal infection builds up in many stands in about 2-3 years from the time defoliation becomes evident, and in combination with other factors such as starvation, parasitism and cool, moist weather causes the sudden collapse of these infestations. Evidence suggests that weather conditions are important in the initiation and spread of a fungal epizootic. High humidity, moderate rainfall, and temperature in the 15.6°C to 21.1°C (60°F to 70°F) range appear optimal (Otvos 1973).

Although the two fungal diseases, either alone or in combination with parasitic insects, are capable of causing the collapse of looper infestations, they generally fail to do so before intolerable tree mortality occurs.

Looper numbers were low from 1971 to 1974 but increased noticeably in 1975 across the Island and light to moderate defoliation was recorded in two localized areas in eastern Newfoundland, suggesting the start of another outbreak. However, an outbreak did not occur, largely because the young looper larvae died of starvation as no suitable food source was available in stands already infested by the spruce budworm. The young looper can only feed on tender new growth, and in forest stands heavily infested by budworm most of the current growth is destroyed by mid-June, about the time hemlock looper larvae emerge from the eggs.

Looper numbers started to increase again in 1977 and 1978, mainly in western and central Newfoundland where budworm numbers decreased. No defoliation was recorded in 1978 but looper moths were observed at widely separated locations. In 1979 larval numbers continued to increase in several parts of the Island but mainly in western, northern and central Newfoundland. Two moderate to severe infestations in mature balsam fir stands were discovered on the Northern Peninsula, one near Salmon River, and the other near Main Brook. At Salmon River defoliation was estimated about 70-80% of the total foliage in small patches of several hectares each, over a total area of 550 ha (1360 acres) of productive forest. About six km (3.7 miles) west of Main Brook severe defoliation occurred on about 330 ha (820 acres) of productive balsam fir forest. Looper adults were numerous in both areas suggesting that both infestations will probably increase in size and may coalesce in 1980. Hemlock looper egg samples (birch bark) have been collected in these areas and eggs averaged 23.1/1000 cm^2.

Light infestations were also recorded in other locations on the Island including balsam fir stands between Jumpers Brook and Norris Arm in central Newfoundland, in the Gros Morne National Park and along the Goose Arm Road in western Newfoundland. Looper moths in high numbers were observed near Indian Pond and McKenzie's Brook south of the Baie Verte Peninsula.

Considering the fact that the spruce budworm has already killed or weakened the forests over excessive areas, the developing outbreak of the eastern hemlock looper projects a very serious threat to the forests of Newfoundland.

SUMMARY

This report consolidates widely scattered information on the six eastern hemlock looper outbreaks reported from Newfoundland in this century. It examines the extent of damage that occurred during these outbreaks and deduces a pattern in the development and decline of looper outbreaks.

The outbreaks are cyclic and they usually develop during warm, dry weather in semi-mature or mature stands with a high balsam fir composition. Outbreaks have recurred at 7 to 18 year intervals and each outbreak has lasted from 6 to 9 years. Outbreaks usually begin as small, scattered infestations which increase in size and distribution annually during favorable weather. Often, these scattered infestations coalesce to form a large irregular outbreak area. Trees may be killed after one or two years of severe defoliation and most of the trees in an infested area are usually killed in the third or fourth year of severe defoliation. Damage is most severe in mature and overmature fir stands, although during epidemic conditions looper populations may "spill over" into adjacent younger stands.

Individual infestations usually collapse in about 2-3 years from the time defoliation becomes noticeable. Weather, starvation, predators, parasites and diseases all contribute to the collapse of looper outbreaks. Studies conducted during the latest looper outbreak provided detailed information on the influence of weather, avian predators, and both the native and introduced parasites, and two entomogenous fungi, and their effect on the course of looper outbreaks in Newfoundland. Weather characterized by high humidity, moderate rainfall and temperature are important in the initiation and spread of two native fungi. A cool wet spring or several days of freezing weather alone may also eliminate or reduce an infestation.

Stomach analysis of birds show that at least 19 species of birds feed on the hemlock looper. Although all stages of the looper reached a high of 46% of the diet in the birds examined in 1 year it is considered that birds are not a major factor influencing the collapse of outbreaks.

Parasites appear to be more important than avian predators in controlling looper outbreaks. One egg parasite and 12 primary larval and pupal parasites were reared from the looper during the recent outbreak. The egg parasite, Telenomus sp., caused up to 23% parasitism while the larval and pupal parasites caused up to 79% mortality of looper larvae and pupae. The latter were composed of eight hymenopterous and four dipterous species; of these, dipterous parasites accounted for all but about 1% of the parasitism. Itoplectis conquisitor, an introduced species, was the most common of the Hymenoptera. Of the Diptera group, Winthemia occidentis, another introduced species, was the most common.

Two native fungi, Entomophthora sphaerosperma and Entomophthora egressa appear to be the primary biological agents causing the collapse

of looper outbreaks in Newfoundland. Data collected during the most recent outbreak indicate that fungal infection builds up in many stands in about 2-3 years from the time defoliation becomes evident, and causes the sudden collapse of these infestations. Evidence suggests that weather conditions are important in the initiation and spread of a fungal epizootic. High humidity, moderate rainfall, and temperature in the 15.6°C to 21.1°C (60°F to 70°F) range appear optimal. Although the two fungi, either alone or in combination with parasitic insects, are capable of causing the collapse of looper outbreaks; they failed to do so before intolerable tree mortality occurred.

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